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ABSTRACT

Recent reforms in science education call for curricula designed to support students' construction of knowledge through inquiry. Teachers need to learn new methods and content to enact reform-based curriculum, and educative materials designed to address teacher as well as student learning are one vehicle for this type of reform. This paper describes the development and use of science curriculum materials that are consistent with constructivist ideas, address national and local goals for student learning, and are educative for teachers. Three middle school teachers with limited experience in physics and project-based science enacted a 10-week unit on force and motion using these curricular materials. The findings of this study indicate that teachers used and learned from the materials and that the educative features that addressed content pedagogical knowledge were used more often and more effectively than those materials that addressed either pedagogical or content knowledge only. (Contains 18 references.) (Author/WRM)

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The Role of Educative Curriculum Materials in Reforming Science Education

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Abstract

Recent reforms in science education call for curriculum designed to support student's construction of knowledge through inquiry. Teachers need to learn new methods and content to enact reform-based curriculum. Educative curriculum material designed to address teacher learning as well as student, is one potential vehicle. Our work is embedded in an ongoing urban systemic initiative of a large public school district to reform science education. As part of this effort, science curriculum materials were developed that were consistent with constructivist ideas, addressed national and local goals for student learning and educative for teachers. Three middle-school teachers with limited experience with physics and project-based science enacted a 10 week, force and motion unit using educative curriculum materials. Classes were videotaped daily and teachers were interviewed periodically throughout the unit. Through qualitative analysis across data sources we found teachers used and learned from educative features in the materials. In addition, educative features addressing pedagogical content knowledge were used more often and more effectively than those that addressed either pedagogical or content knowledge. Our work indicates educative curriculum can facilitate teacher learning necessary for improved practice and informs development of materials for all teachers as well as those participating in urban reform.

Introduction

Science education is the focus of many reform efforts. Specifically, reformers are suggesting that teachers utilized inquiry based, student centered instructional practices that will facilitate students' construction of knowledge. Embedded technology use to support students in a deeper understanding of fewer topics is encouraged. In addition, reforms for science education based on these recommendations, are being attempted on a large scale. Many states and school districts have made science education a part of their overall reform efforts to improve instruction for students in their schools. However, reform-based curriculum designed to support students' construction of knowledge in science through inquiry relies on teachers to fulfill this vision for our students. For many teachers this will mean substantial changes in instructional practices. Since what teachers do in their classrooms depends largely on their knowledge, teachers will need to learn a great deal to be able to enact reform-based curriculum (Wallace & Louden, 1998; Borko & Putnam, 1996). Teachers, like other learners, will need supports. Educative curriculum, curriculum materials designed to address teacher learning as well as student learning, is one potential vehicle (Ball & Cohen, 1996). Our work is imbedded in an ongoing urban systemic initiative of a large public school district to reform science and mathematics education. As part of this effort, science curriculum materials were developed that were consistent with constructivist ideas, addressed national and local goals for student learning and educative for teachers.

Theoretical framework

An approach to science instruction that addresses the concerns of reformers is Project-based Science (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Project-based Science involves students in extended inquiry as they investigate answers to a driving question. Integrated uses of technology along with collaboration among learners are important components that allow students to develop understanding of science, which they demonstrate through development of artifacts. We have developed curriculum materials based on the premises of Project-based Science. Our curriculum design is based on principles that are consistent with what is known about teaching and learning. These include: alignment with standards, contextualization, sustained student inquiry, embedded learning technologies, collaboration, assessment techniques, and educative materials for teachers. Curriculum materials created by using these design principles can promote deep understanding of science concepts and inquiry strategies and address the needs of diverse students (Krajcik, Blumenfeld, Marx, & Soloway, 1999). However, enacting reform-based curriculum is not easy. Specifically we know that Project-based Science curriculum presents several challenges to teachers. Common challenges faced by teachers have been found in several schools with teachers enacting Project-based Science (Marx et al., 1997; Scott, 1994). Challenges included teachers' knowledge of: inquiry versus a more linear flow of information, various techniques to promote learning such as coaching or modeling, specific instructional strategies such as prediction-observation-explanation, management of the classroom, science understanding of non-trivial content, new technologies to represent content and support inquiry, and non-traditional assessment. Teachers' ability to enact reform-based curriculum such as ours depends on their learning new instructional practices.

One way to support teacher learning is through curriculum materials designed to be educative for teachers (Ball & Cohen, 1996). Curriculum materials including textbooks, teacher guides and technology-based materials, whether supplied by publishers or researchers, have traditionally been designed with student learning as the goal. However materials can be designed to support learning by teachers as well as by students. Educative curriculum materials are designed to support teacher learning, as the materials are used by teachers to support student learning. Educative curriculum materials cannot replace other professional development opportunities but they do have a unique role. Unlike summer workshops or peer collaboration, teachers will be able to use curriculum materials over an extended period of time in the context of their classroom. Teachers are also accustom to using such materials to plan and structure student activities (Ball & Cohen, 1996). Teachers' use of educative curriculum materials in the classroom with their students may help to situate teacher learning (Borko & Putnam, 1996; Brown, Collins, & Duguid, 1989). In addition, because curriculum materials are used in nearly all schools, by nearly all teachers, they can be used to address reform issues on a large scale.

Designing Educative Materials

Although many reform-based curricula are being developed, they have not been explicitly designed to support teachers' learning. It is not enough, however, to give teachers directions on how to enact curriculum (White & Frederiksen, 1998). Ball and Cohen suggest curriculum materials can be educative for teachers by offering support for teachers in thinking about: 1) content beyond the level suggested for students 2) underlying pedagogy 3) developing content and community across time 4) students and 5) the broader community. For reform in science to be successful teachers will need to learn new classroom practices. A framework of knowledge areas necessary for exemplary practices has been proposed (Shulman, 1987). Shulman includes three main knowledge types: content, pedagogical, and pedagogical content knowledge (PCK). For science teachers PCK includes knowledge of science specific strategies, various ways to represent content and students' thinking about science ideas. Because our curriculum materials are intended to be used by teachers as they plan lessons for their students, teachers will need to access knowledge of content and pedagogy as they think about their students in a particular context.

Keeping in mind Ball and Cohen's suggestions for educative curriculum as well as known challenges to inquiry-based curriculum (Marx et al., 1997), we included features intended to be educative for teacher within our curriculum materials. We also attempted to take advantage of the situated nature of curriculum materials by linking the content of the support to the lessons for students. We used the voice of a teacher or students involved in this lesson to illustrate or model the intended practice when possible. Because teachers could use our materials to plan lessons that would be enacted within a short time, the educative features surrounding and embedded in the lesson could address the immediate needs of the teacher for learning support. Educative features in our materials included: science content explanations for the teacher beyond the level of understanding suggested for students, overviews of the entire unit and portions we called learning sets to explain the reasoning behind the sequence and flow of the lessons, short scenarios to

illustrate how an idea or activity may be introduced in connection to other ideas, support for using artifacts as assessment tools at the beginning and end of lessons, and notes to the teacher embedded within lessons. The embedded notes addressed the specific strategy and how it supports student thinking, the representation and how it represents science content to students, and student ideas involved in the lesson such as probable prior knowledge or experience, responses and demonstration of understanding, and appropriate level of understanding and concepts that are challenging for students (Appendix A).

Creating materials with teacher learning in mind is a new idea and is yet to be well developed or researched. Although other materials may include some features that are educative for teachers, currently only two curriculum projects claim that they have developed educative curriculum materials. One of these projects is the focus of this study. The other is a mathematics curriculum for elementary students designed by TERC (TERC, 1995). One of the goals for their elementary mathematics materials, Investigations in Numbers, Data and Space, is to communicate mathematics content and pedagogy to teachers. Research using TERC's materials showed educative curriculum materials to be a promising vehicle to contribute to teacher learning (Collopy, 1999). Collopy's study however followed only two teachers as they used TERC's materials with their 5th grade students. One teacher used the materials and changed her practice to include more constructist ideas. The other teacher however discontinued using them and after an initial attempt at new practices reverted to more traditional methods. Educative curriculum material is an intriguing idea and our research contributes to our knowledge of how and in what areas could these materials could be helpful to teachers.

Our Questions

Although we do know that teachers need to learn new methods and content to enact reform-based curriculum, we do not know what role educative curriculum materials might play in supporting their learning new practices in the classroom over time or how such materials should be designed. We have proposed design considerations based on research in teacher knowledge and learning and have developed materials based on this model. To continue our work in developing materials for teachers we need to find out how the use of our educative curriculum material influences teachers' practices. This study was guided by three sub questions 1) how do teachers use our educative curriculum materials, 2) what do teachers understand when they use our educative curriculum materials, and 3) how do teachers' classroom practices change when they use our educative curriculum materials. Each of these questions plays a role in answering the question of this study. What is the role of educative curriculum material in supporting reform-based practices in science education?

Educative curriculum features were included in the curriculum materials given to teachers. We attempted to design curriculum materials that were not teacher proof (Apple & Jungck, 1990), but would guide teachers in experiences that would enable them to construct knowledge about teaching and that would enable them to implement reform-based instructional practices. Also, we encouraged teachers to modify curriculum to meet the needs of their students and circumstances. Educative features that address areas that have challenged teachers new to this type of curriculum in the past (Marx et al., 1997)

and recommended by Ball and Cohen (1996) were included in these materials. Our science materials included information to explain content and pedagogy, as well as specific information about strategies, representations, and students' ideas (PCK) embedded within lessons. We utilized Shulman's three main areas of teacher knowledge to examine teachers' use of and learning from the curriculum materials. The potential of educative curriculum materials to support teacher learning will be illustrated by the description of how teachers' practice is influenced by the use of our educative curriculum materials.

Methods

Designing curriculum materials to be educative for teachers is a new idea and almost no research has been done in this area. Therefore methods for this study were chosen based upon logic of our questions and established methods used to study teacher knowledge in classrooms (Borko & Mayfield, 1995; Grossman & Richert, 1988; Krajcik, Blumenfeld, Marx, & Soloway, 1994). Our research design combined teacher interviews and classroom observations over time. By observing teachers' practice in the classroom and interviewing teachers about their plans and reasons for the lessons we gained information about what teachers understand from educative curriculum materials. Likewise, data on the influence of educative materials and their use by teachers was collected both through observation and teacher interviews. We examined teachers' use of educative features in curriculum materials and their classroom practices across a 10-week unit on force and motion. Using the intended curriculum as a guide, we looked for connections between use of materials, support by educative features in the materials and teacher practices in the areas of content, pedagogical, and pedagogical content knowledge.

Background

This study was embedded in a National Science Foundation funded urban systemic initiative to reform science and mathematics instruction. Project-based science curriculum materials for a unit on force and motion were developed as part of the larger study. Teachers participating in this reform effort were supported by a one-week summer institute, three Saturday sessions and weekly in classroom support offered by both university and school personal. The educative curriculum features of the materials were only one part of the professional development involved in this reform effort. This study was conducted in three urban middle schools located in low SES neighborhoods selected to participate in initial stages of the reform effort. Students in these schools were over 95% African-American and scores on statewide standardized testing in science were reported as below grade level.

The curriculum materials used in this study were developed to involve 8th grade students in a 10-week extended inquiry. They investigated the driving question, "Why do I need to wear a helmet when I ride my bike?" Use of motion sensors with computer interface was integrated along with collaboration among learners to allow students to develop understanding of Newton's 1st law, velocity, acceleration and force. Students developed various artifacts to both develop and demonstrate their understanding. Teachers were introduced to these materials during the one-week summer institute.

Teachers participating in this study were experience in-service teachers that had volunteered to participate in both this study and the larger reform effort. The teachers enacted the force and motion curriculum for the first time during the fall term in several of their classes. Sections were chosen for observation based on compatibility with times staff could be in the school to collect data and provide support. All three teachers were African-American females with teaching experience of 1, 7 and 17 years. Their preparation and certifications were respectively: elementary science, middle school biology, and elementary mathematics. Prior to the project, teachers had limited experience with project-based science, physics and the use of technological tools to support inquiry.

Educative Features of the Materials

The curriculum materials included teacher's materials and student worksheets. In the teacher's material the unit was divided into 5 sections called learning sets, based on main ideas. Each learning set consisted of several 1-3 day lessons. Teacher's materials included educative features for teachers in the areas of content, pedagogy and pedagogical content knowledge (PCK) (Appendices A and B).

Teachers were given content support before each learning set of the unit to help them understand Newton's 1st law, velocity, acceleration and force beyond what was suggested for student understanding. For example content support for teachers included the idea that standing still could also be thought of as a constant velocity with a value of zero thus combining constant motion and standing still in one definition of acceleration. Lessons for students listed constant velocity and zero velocity each time the idea of acceleration was addressed.

Pedagogical support included help in understanding the sequence and flow of the lessons and assessment through artifacts. Descriptions of the unit and each lesson were given before lessons to explain how and why lessons were sequence to connect and develop both ideas and skills. For example teachers were supported in understanding the concept of force was addressed early in the unit to help students think about Newton's 1st law but force would also be addressed again later in the unit to link ideas of mass and changing velocity. Explanations of how students would use ideas to develop artifacts, which could be assessed for understanding, were offered both before and after lessons. For example a suggestion that students' explanation of their computer generated graphs could be evaluated to determine students' readiness for the next lesson was included at the end of the first lesson using motion sensors.

Educative features to address PCK were embedded within each lesson. These supports targeted: 1) how to use the specific strategy, how it develops science content ideas and how it supports student thinking, 2) how to use the specific representation, how it represents science content ideas, and how it supports student thinking, and 3) student ideas involved including probable prior knowledge and experiences, probable responses and demonstration of understanding, and appropriate level of student understanding and challenging concepts. For example a note to the teacher explained the importance of

students observing the computer screen while walking in front of a motion sensor, as this would help the student to link motion to the resulting graph.

Data collection and analysis

One class period throughout the unit for each teacher was videotaped during enactment of this unit. Two teachers were videotaped daily and the third periodically. Descriptions of teacher practice were written for each videotape based on consistency with those recommended in the curriculum materials and addressed by educative curriculum features as described above. Teachers were interviewed just prior to enacting selected lessons and again just after the lesson. Questions targeted plans for instruction, adaptations, and reasons. Sample questions included: how do you envision helping student to understand velocity, what would you change about this lesson, and what did you need to know to make this lesson work. Teachers were also asked what features of the material they found helpful or would recommend and how they used the materials (Appendix C). Data was combined across teachers to find patterns in how the educative features were used and how lessons were enacted as evidence of teacher learning through educative features for pedagogical, content and pedagogical content knowledge. Individual differences in use of educative materials and practices were examined.

Findings

Teachers' Use of Educative Materials

Each teacher reported using the educative materials to help them understand the intended instructional practices and science content. We also have evidence from classroom enactment that teachers used educative features offered in the materials. Teachers used specific information, given in educative features, with their students in class. For example one teacher stated to the class "I know that some of you are thinking that the increasing the mass will cause the cart to go faster." This information was part of an educative feature on how students think about acceleration due to gravity. Each teacher was also emphatic about the fact that they were much more focused on the materials when they were reading them immediately prior to enactment. "If I say they're [the materials] not as helpful it is because I read them in isolation, it doesn't hold my attention and everything as much as if I was getting ready to actually do this." This teacher had read the materials on Saturday for this conversation on Monday. The lesson being discussed would be enacted on Tuesday morning. Teachers also mentioned that the educative features specific to the lesson at hand were particularly helpful such as what students' computer generated graphs would look like and how the graphs would illustrate slow, medium and fast motion. Suggestions for additional educative features were usually for features embedded with lessons. However, most suggestions were for additional resources such as transparencies or easier to read formats such as pictures of student sheets included in teacher's materials.

Individual Differences

Individually each teacher used the materials differently. One teacher, 17 years experience, described thinking about what a student might think during a lesson as she read the materials. She also thought about how the lesson would help students understand a concept or what they might have trouble understanding. In reference to reading a lesson

about motion sensors and graphs she stated, "what I do when I read it, I got the big idea then I work through this again in my mind and say now if I were a student and I didn't have all this information what would I think. Then I jot that down for myself." Another teacher, 1 year experience, read the materials and paid attention to information about students but focused on what she could expect students to do in response to lessons. "I like how some of the comments are your students may say so and so, I think that is helpful for someone who is doing this for the first time." She also seemed to see the curriculum rather than herself as the guide for the students. "They know POE [prediction-observation-explanation], I want them to just do it themselves. I want them to be more responsible for their learning, that's their job." The third teacher, 7 years experience, also used the materials at the beginning of the unit; however, early on she began to rely on the student worksheets as a guide rather than the teacher's materials. She said she did this because it was easier to find out what she should make sure students completed. "Before class I would look at the student sheets. They have what the students will be doing, with this book [teacher's materials] you have to read a couple of pages before to figure out what is going to happen that day." This teacher reported that when she did refer to the materials, content support was the most important feature for her.

Teachers' Content Knowledge

With respect to the areas of teacher knowledge, each teacher demonstrated different levels of understanding physics content, pedagogy related to Project-based Science practices, and PCK, but some general patterns were evident. In the area of physics content understanding, which was supported at the beginning of each learning set, some teachers were more proficient than others but all struggled with more complex ideas. For instance, teachers generally understood velocity, were able to talk about it accurately and gave many appropriate examples. "When your parents are driving you to school, when they are late they go faster. They cover a greater distance in an amount of time." This teacher also sketched a position-time graph on the board with two positively sloped lines and explained, "the steeper one is faster, the steepness indicates how fast you were going." However she then struggled with the difference between velocity and speed. "If they were going backward that would not be velocity, backing up the car. Speed cannot be velocity when going backward. Velocity can go backward. Positive velocity is related to speed." This teacher had obviously read the content support describing the directionality of velocity but without complete understanding. Other teachers also gave evidence, as this example shows, of using content explanations for the teacher with their students in class even though the explanation went beyond what was suggested for students. However, when teachers were working with students and their resulting graphs content explanations were more direct and clear. Interestingly, teachers also reported learning specific content from notes about how students may understand a particular science idea. One teacher said she learned about physics from reading the notes about students' misconceptions because she held some of those same misconceptions herself. Each teacher also noted that the content explanations were a good reference because they were easier to read and locate than a physic text.

Teachers' Pedagogical Knowledge

There was also a variation in the level of pedagogical understanding. Support for understanding the sequence and flow of the lessons and how content ideas and skills were developed and connected was extensive. This support was offered for the unit as a whole, for each learning set and for each lesson. But teachers in general did not report reading these descriptions. While teachers were concerned about their own content understanding they did not show the same concern for understanding how this unit would develop these ideas. Teachers' practices also indicate that they had difficulty connecting ideas from different sections of the unit. They did not necessarily see opportunities to discuss content other than the targeted ideas of the lesson and treated each content idea as discrete. One tool used to connect ideas in this unit was the driving question. Teachers would refer to the driving question by asking, "how does this idea relate to the driving question." Rarely did they ask how does this concept, which helps to answer the driving question relate to this previous concept, or what does our question guide us to think about next. Concept mapping, an important activity repeated 3 times across the unit to support students in developing connections between concepts was the most often omitted activity. This was in part due to teachers' unfamiliarity with concept mapping. However teachers were also unfamiliar and uncomfortable with computers yet none of the activities using computers were omitted by anyone. Technology based lessons each introduced and explored specific content ideas. Concept maps integrated ideas already introduced.

The teacher with 17 years experience was the only one to mention reading the overviews and thought they were good. She was also the only teacher to use concept mapping. On the first occasion she spent 3 days with her class developing concept maps and encouraging students to relate ideas, "I want to see lots of relationships." After this lesson she stated that she and her students thought they understood everything about Newton's 1st law, but they did not really understand it until they created their concept maps. Unfortunately, later in the unit when time had become an issue she did not return to this activity.

Teachers had similar difficulties with assessment through artifacts. Three main artifacts were to be developed by students throughout the unit to support students in developing their ideas and to demonstrate these ideas to teachers. Again educative features addressing artifacts were included both before and after lessons. The role of each artifact, when and how students should develop them, and how they would demonstrate student understanding was explained. One of these was the concept maps discussed above. The other two were an investigation of an egg helmet and a 5-part essay describing force and motion. The essay was used by all teachers at the beginning and end of the unit but not revisited during the unit. Everyone completed the investigation during the last days of the unit. Teachers did not appear to understand the role of developing artifacts over time.

They also did not see artifacts as assessment opportunities until the end of the unit. The experienced teacher understood what students should be able to do in a lesson and monitored each student regularly. The teacher with 1 year experience read the materials describing what students' velocity-time graphs would look like, how graphs

could be read to interpret changing motion and how students would respond if they understood the graphs. When asked how she would be able to know if students understood the graphs when she did this lesson on the next day, she was able to describe what questions she could ask and what she would expect students to answer. But when asked if she planned to do this she paused then said "I guess I could do that, maybe, now that you mention it maybe I should do that. Maybe I will." Although she understood the representation and student ideas (PCK) she did not understand assessment, that this was an opportunity or that she should monitor students understanding prior to the end of the unit. Our third teacher created traditional quizzes to supplement the unit, in part as behavior management technique.

Teachers' Pedagogical Content Knowledge

In the area of PCK, supported by embedded notes within a lesson, teachers were able to use specific strategies and representations with their classes. Teachers were generally successful in contextualizing individual lessons with real life examples and referring to the driving question as described above. Specific strategies, such as prediction-observation-explanation, and specific content ideas, such as velocity, to be represented were explained in notes to the teacher as well as how students might use this lesson to build understanding. Teachers who read these materials could describe how POE could support student learning although the experienced teacher was more skillful in enacting the POE cycle. By contrast, the teacher who discontinued reading the materials did not appreciate the value of explaining one event before making a prediction about another. Rather than cycles of POE she had students complete a group of predictions then do the activities. The explanations were assigned as homework.

Teachers also used the recommended representations to help students understand ideas. Noteworthy is their use of motion sensors with computer interface. All teachers had little to no previous experience with technology and were initially apprehensive about using computers in their classroom in spite of work during the summer institute. However each was successful in having students use motion sensors to explore motion and design investigations. Use of motion sensors was embedded in specific lessons to represent specific content with a specific strategy. Teachers were able to use information in the materials to learn how to help their students make sense of the content represented in their graphs.

Discussion

Few curricula have been developed to be educative for teachers as well as students. But since reform-based curriculum, such as ours, depends on teachers' enactment we were interest in the role educative curriculum material in supporting reform-based practices in science education. All of our teachers were new to this curriculum, physics, and project-based instruction, yet those who used educative features in the materials were more successful in interpreting the curriculum into practice. Teachers used our educative materials most when planning, focused on what they needed to know to enact a lesson with their students, and thus attended to educative features closely related to a specific lesson. Interview and observation data both suggests that teachers understood lesson specific ideas (PCK) better than content or pedagogy when

using educative materials. Teachers' practices were more consistent with those intended for specific lessons than they were for the unit overall. Teachers used lesson specific educative features, understood lesson specific ideas and reflected this in changing lesson specific practices.

This evidence on use and influence on practice suggests that pedagogical content knowledge may be a useful construct for designing educative curriculum materials. Teaching is a complex activity that requires teachers to understand content and pedagogy as they come together to support student thinking and learning in the context of their classroom (Magnusson, Krajcik, & Borko, 1999; Shulman, 1987). Educative materials are uniquely situated in the classroom, unlike other professional development opportunities. Perhaps to best take advantage of educative materials to help teachers learn would mean addressing knowledge that is also uniquely situated in the classroom. Because curriculum materials by definition are about specific lessons it is more difficult to support content and pedagogy but much easier to support PCK. This is reinforced by the fact that teachers use these materials to plan for their students in the immediate future. Other, broader areas of teacher knowledge should be address in professional development opportunities outside of the classroom. This is in agreement with others who found that teachers attribute learning pedagogy and content in university settings, and pedagogical content knowledge in their classroom based experiences (Borko & Mayfield, 1995; Grossman & Richert, 1988). Particularly in science, because educative features can be embedded in a specific lesson they naturally would address a specific strategy to use with a specific representation of content and how students will think about the lesson. The lesson, with its educative features embedded, is thought about and enacted by teachers with their specific classroom context in mind.

It is important to recognize that this study was conducted with only 3 teachers, one of whom stopped reading the materials early on. Therefore, although we have gained some insights, many more teachers will need to participate in using educative materials in order to make conclusions such as ours more convincing. Years of teaching experience was also related to each teacher's practice, but did not fully explain the observed difference. It is true that the teacher with 17 years of experience did make the most of the opportunity to learn, but the teacher who discontinued using the materials had 7 years experience. The teacher with only 1 year of experience read the materials and made gains in understanding in each area. Her lack of experience may explain her struggle with putting plans into action and thinking about students' thinking, more than it explains how well the materials were used for planning. Therefore, although we have gained some insights, many more teachers will need to participate in using educative materials in order to make conclusions such as ours more convincing.

The teacher who discontinued use of the materials did help to highlight the value of the materials by offering a contrast of what enactment might look like with workshop and in class support as the only professional development. The fact that there were other sources for content, pedagogical and pedagogical content knowledge might otherwise be a larger limitation for this study. In addition the areas where teachers had the most success, specific lessons, were the areas less emphasized in the workshop. Classroom

support tended to focus on things such as how to operate the computers or manage student notebooks. Teachers' statements about their use of the materials also helps to point us to the educative features as a source of some of their understanding. A research design with a greater focus on specific educative features and how teachers think when reading them would give us more information about how to better design such materials (Ericsson & Simon, 1993).

Educative curriculum material appears to be a promising approach to facilitate teacher learning that is necessary for improved practice. In order to create such materials, however, much research needs to be done. We have little empirical evidence to guide us in the development of such materials. This study begins to identify what knowledge is best conveyed with educative curriculum materials and how teachers might use these materials. Further research in this area along with studies on what prerequisite skills or knowledge is needed, and how student learning is enhanced when teachers use educative materials is needed. This will inform the development of materials for all teachers as well as those participating in urban reform.

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Apendix A

Teacher knowledge and Educative Features

Content

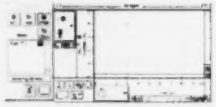
Topic in this Curriculum	Educative Features	Examples
Force Newton's 1st Law Velocity Acceleration Variables Motion Graphs	Science Understanding for the Teacher: Explanation of science content to a level beyond that suggested for students, included at the beginning of each Learning Set	When an object is moving such as a student on a bike or an egg on a cart, it is changing distance per time in a certain direction. This means that at each consecutive time interval the object is at a different location. The rate of changing distance per time in a direction is the object's velocity. Velocity is the change in position over change in time. Speed is a component of velocity. Speed is the change in distance over time. Velocity can be positive (forward) or negative (backward). The positive or negative indicates direction. Speed is always positive number because it measures how much motion but not the direction.

Pedagogy

Topic in this Curriculum	Educative Features	Examples
Sequence and Flow of Lessons	**Overviews** describing how concepts are linked and developed through lessons and across the unit. Overviews of entire unit Overviews of learning sets	Students participate in several **investigations** while exploring each stage of the driving question. Students begin by examining the design of an investigation and gradually develop the ability to design their own investigations. They first focus on experimental variables as they explore the relationship between mass and Newton's first law. As students continue their exploration of motion, **motion sensors** are used to create computer-generated graphs. Students develop understanding of velocity, acceleration, as well as how to read and interpret motion graphs. Next the investigation of gravity and mass focuses on collecting and interpreting data again with the use of **motion sensors** to determine changing velocity. When students investigate the relationships between force, mass and acceleration they select independent, dependent, and control variables and focus on conclusions. Students will use **motion sensors** again in their own investigation of their egg helmets. Learning Set One illustrates for students what can happen without the protection of a helmet. Students first hear one boy's personal experience with critical injury in the video *Jell-O in a Jar*

		and share their own experiences with bicycle riding and perhaps accidents. Students are then given a common experience when they watch an egg ride a cart down a ramp without a helmet. This event will guide students' inquiry through out this project as they explore what happens in a collision. Below are the main instructional events for this learning set.
	Overviews of lessons	Students then observe the egg and cart demonstration again and use the concept of Newton's 1st law, force, velocity, and acceleration to explain the process of the egg getting pitched off the cart and getting into an accident. This discussion raises the question ""When I get pitched off my bike, why do I get hurt?" This question becomes the focus question for the next part of the inquiry.
	Short scenarios in the voice of the teacher or student to illustrate how an idea or activity may be introduced in connection to other ideas.	Over the last couple of sessions we have observed a number of demonstrations and have done a few experiments to help us answer "How fast was I going when I got pitched off my bike?" You have just brainstormed a list of ideas and concepts that you have learned. Now you will continue to construct the concept map that you began in learning set one to show how all the ideas or concepts you learned are related. As before you will first work independently to make a list of statements that relate one concept to another and then you will actually construct your map.
Artifacts as Assessment Tools	**Artifact assessment explanations** at the beginning of lessons.	After an initial explanation of a collision. Students' stories about motion and their explanations can be assessed to determine their initial understanding of motion and collisions. This will help both you and the students to observe their progress in developing understanding during this project.
	Artifact assessment explanation at the end of lessons	After a graphing activity. Look at the graphs that students have created today. You can assess their ability to use the motion sensors as directed. This is an importatnt skill as students will be using these sensors repeatedly in this and the following learning sets. Make sure everyone can pick up their motion with the sensors, are not starting or ending too close to the sensor or moving to the side resulting in graphs that jump around or "flat line" indicating that the student was not in front of the sensor. Also check that they can resize the graph and read the numbers for positionor time from their graph. This will mean they are ready to go on the next activity. You will not need to read every prediction and explanation do check these things. You will also know which students will need more assistance in the next activity.

Pedagogical Content Knowledge

Topic in this Curriculum	Educative Features	Examples
Science Specific Strategies: POE • How strategy supports student thinking	Notes to the teacher embedded within lessons	For a graphing activity using motion sensors. Make sure that student refer to their first set of motions and graphs to make thoughtful predictions for these motions. For an egg and cart demonstration of a collision. Students will enjoy this demonstration, particularly the crash. It will be important for you to focus their attention to the different aspects of the motion and the collision. Predicting and creating motions from graphs and graphs from motions allows student to practice their newly acquired skills in reading graphs and thinking about motion. For an initial egg and cart demonstration of a collision. Again students' explanations will be sketchy and use terms incorrectly. These explanations are important to make explicit the ideas that students have about motion to both you and the students
Representations of science concepts • • How content is represented to students		Slope: This is a good opportunity to reinforce the concept of slope. Slope is rise over run or for a change in y there is a corresponding change in x. The greater the change in y for a given change in x the greater the steepness of the line therefore the greater the slope. For our case it means a greater change in position for a certain change in time. This graph further emphasizes that the graphs produced for each motion are plotting two things: time and position. Position being the distance that the student is from the sensor. If the student stands still than their position remains constant and is plotted as such. Time still passes so time is plotted resulting in a horizontal line.  It is important that students see that you are watching the graph as it is being created by the computer. When students create their own motions, if they watch the graph and feel their own motion at the same time they will be able to connect motion to the illustration of the motion much easier.

Student thinking • Probable prior knowledge or experiences • Probable responses • Demonstration of understanding, appropriate level of understanding, and challenging ideas.		Many student will think that any object in motion experienced a force at one time and that objects at rest have not experienced a force. When the egg was moving faster, students may mention that the egg hits harder implying more force is involved when moving faster. Another point that may confuse students is the relationship of force to motion. An unbalanced force on an object will cause a change in motion. Some students think that if an object is in motion that there is an unbalanced force on it. This is not true if the object is at a constant velocity.

Appendix B

Sample Educative Curriculum Materials

Learning Set Three:
How fast was going when I got pitched off my bike?

Learning Set Purpose

- Develop understanding of velocity using motion sensors to visualize motion.
- Read and interpret position-time graphs.
- Operationally define acceleration.
- Integrate and refine understanding of velocity and Newton's 1st law.
- Relate velocity to the anchoring experience and the driving question.

Learning Set Overview

This learning set leads students to look more closely at motion. Beginning with the anchoring egg and cart demonstration students ask how fast is fast? Students will explore velocity as they use motion sensors to create position-time graphs of their own motions. Students then gain personal experience with velocity both constant and changing when they observe the effects of their motions on motion detector. All of these concepts are then related back to the anchoring egg and cart experience. Below are the main instructional events for this learning set.

Graphing Motion. Motion sensors are used to create graphs to visualize motion. Students move at various constant velocities to explore position, time, and slope.

Motion Detectors. Student make motion detectors out of common household items to take home and carry for several days. Students observe the affects on their motion detector of a variety of motions, both constant and changing velocity.

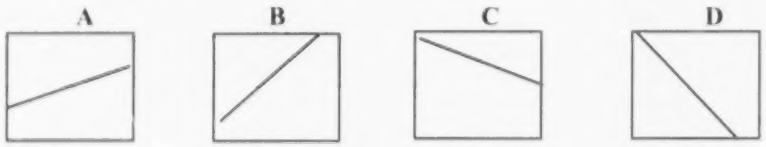
Science Understanding for the Teacher

Velocity is the change in position over change in time. Speed is a component of velocity. Speed is the change in distance over time. Velocity can be positive (forward) or negative (backward). The positive or negative indicates direction. Speed is always positive number because it measures how much motion but not the direction.

Graphs can be used to illustrate motion. A position-time graph is a plot of an object's position as time increases. This graph shows changing position over time. Changing position over time is velocity. This is why a position-time graph might also be called a velocity graph. A position-time graph will have a straight line if the velocity of the object is constant. This is because the rate of position change is steady.

The slope of the line indicates the velocity, small slope represents small velocity and large slope represents large velocity. This is because as time increases the faster the object is moving the farther away it will be after the same amount of time. Compare graph A to graph B and graph C to graph D below.

The direction of the slope indicates the direction of the velocity, positive (up) slope represents positive (forward) velocity and negative (down) slope represents negative (backward) velocity. This is because as time increases the object will be farther away if it is moving away from the reference point (see graph A or B) or closer if it is moving toward the reference point (see graph C or D).



	A	B	C	D
Slope	small & positive	large & positive	small & negative	large & negative
Velocity	slow & forward	fast & forward	slow & backward	fast & backward

The standard units used to measure position are meters and for time seconds are used. Therefore the standard units for velocity are meters per second (m/s). Any units can be used for position and time and therefore velocity but they must always be specified.

Velocity is important to our driving question because it will lead to the understanding of acceleration. Acceleration is the change in velocity and is related to the amount of force feel by an object such as the egg when its motion is stopped.

Purpose

- Develop understanding of velocity using motion sensors to visualize motion.
- Read and interpret velocity-time graphs

Time

four fifty-minute periods

Materials

steel inclined plane
cart
eggs
support stand
2 support rods
clamp
Dixie cup

motion sensors
universal laboratory interface
computer
masking tape

Student Sheet: How Fast is Fast?

Source
Adapted from P. Laws, D. Sodoloff, & R. Thornton. 1993-1994. Real Time Physics. Tufts University.

Session One Velocity

During this session students learn how to describe motion and explore the concept of velocity. Students explore velocity in the context of the larger learning set question "How fast was I going?" The egg and cart anchoring demonstration is repeated several times with the height of the ramp increasing and thus the velocity of the cart. As the damage to the egg increases, questions such as "So how fast is fast?" and "What do we mean by fast?" are raised. Students explore the qualitative nature of velocity by using motion sensors to make instantaneous position-time graphs of their motion. This allows students to develop the understanding that velocity involves two measurements, position and speed. Students' understanding of velocity graphs are reinforce as students are challenged to both create a motion to match a given graph and to create a graph to match a motion description.

Session Preparation

1. Set up and practice egg and cart demonstration to find about three different ramp heights that result in various degrees of egg damage.

2. Set up and practice using motion sensors.

3. Prepare student sheets How Fast is Fast?

TS

Students do not have experience with the probes so for the first experiment students will have difficulty making predictions. To facilitate this process have students perform motions 1 and 2 and then make a prediction for motion 3. They will be able to make predictions for all subsequent experiments.

***Sample Response**: The graphs shows me moving away from the probe. Distance is on the y-axis. Time is on the x-axis. I started 0.5 meters from the probe and I ended up at 5 meters from the probe. The graph is a straight line.*

***Sample Response**: The graph of me walking away from the probe slowly is less slanted than the graph of me walking away from the probe slowly. The last graph is steeper than the first graph. This is because I was moving faster.*

***Slope of the d-t graph equals velocity**. Each motion produces a straight line. If you look at all three graphs at the same time you*

Moving Away from the Motion Probe

Read Students read the motion they will perform.

Motion 1

Start 1/2 meter away from the motion probe and make a distance-time graph, walking away from the probe slowly and steadily.

Motion 2

Start 1/2 meter away from the motion probe and make a distance-time graph, walking walk away from the probe medium fast and steadily.

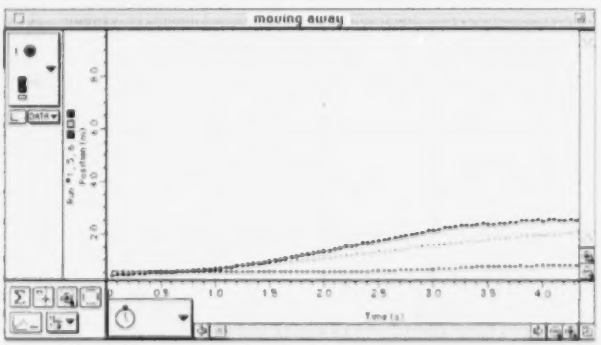
Motion 3

Start 1/2 meter away from the motion probe and make a distance-time graph, walking away from the probe fast and steadily

Predict Students make a prediction of the distance time graph of the motion. This prediction should be sketched on their "How fast is fast?" students sheets.

Perform Students perform each motion.

Print Student make sure that all three runs are selected and print the graph. They then label each run, 1, 2, and 3 on their graph.



will notice that the faster the student walked the steeper the line. The steepness of the line is called the slope of the line. So the slope of a distance-time graph is equal to velocity. As velocity increases the slope of the distance-time graph increases. Also all the lines on the distance-time graphs slant upward to the right (known as a positive slope) because you are moving away from the probe.

Posting Concepts: *As each concept is identified post it on the board or on butcher paper. Post: fast refers to velocity, steepness refers to slope, and slope of the distance-time graph equals velocity.*

Slope: *This is a good opportunity to reinforce the concept of slope. Slope is rise over run or for a change in y there is a corresponding change in x. The greater the change in y for a given change in x the greater the steepness of the line therefore the greater the slope. For our case it means a greater change in distance for a certain change in time.*

Each motion should produce a relatively straight line with a positive (upward) slope. As each motion becomes faster the line produced should become steeper.

Explain Students write an explanation of what each of the lines on their graph shows individually and collectively.

Questions for Each Motion

- What is on the x-axis and y-axis?
- What was their initial position for each run?
- What was their final position for each run?
- What is the pattern or trend of the graph of each run

Questions for Between Motions

- Describe the difference between the graph you made by walking away slowly and the one made by walking away more quickly.
- Compare graph ONE to TWO, ONE to THREE, and TWO to THREE. What trends do you see?

CLASS DISCUSSION

Home Session

Students develop their own understanding.

Provide students with an engaging experience that represents some scientific phenomena. In this case students will make observations of acceleration.

Accelerometer student sheets.

Acceleration is any change in direction or velocity. If a change in velocity or direction is experienced by the bottle the bubble or the cork will move away from center showing acceleration.

Give each student an accelerometer or give them directions to make them at home.

An accelerometer consists of a plastic pop bottle filled with water leaving a small amount of air at the top. When the top is securely fastened and the bottle is inverted a bubble will be at the center of the bottom.

Accelerometers can also be made by using an empty peanut butter or other type of jar. Fill the jar 3/4 full of water. Attach a cork or other buoyant object to the lid with a string or cord that is as long as the water is deep. When the lid is screwed on and the jar is inverted the cork should float at the surface of the water and the string should be taunt.

The students take the accelerometer home with them for a few nights. Instruct the students to keep the bottle with them for the next two days and watch the bubble or cork as they walk, ride in the car, or otherwise travel. Students observe the bubble or cork in multiple situations. If the bubble is on center or off center students must record this on their chart, note the situation they were in, and write an explanation for why they think the bubble remained in the center or moved off center. Students must record two situations where the bubble was on center and three when it is off center.

Students will use this home activity for Session 2.

Appendix C
Teacher Interview Questions

Pre-enactment Interview

Teacher reads an excerpt from the materials. Read the materials think about what the materials are telling you about how to teach this session. I would like to ask you questions about a specific learning set and session pages

Questions: We are trying to understand, with your help, how to write these materials so that people will be able to take something away with them (learn) from having read these materials. It is helpful to us to know what helped you to understand and what was useful in the way we set it up. Was it useful and in what way?

Describing: How the teacher interprets the materials.

1. The materials describe (specific strategy) to help students learn about (specific content). what does this mean to you?
    - How did the materials help you to learn about (specific strategy) to help students learn about (specific content)?

2. What are some of the suggestions in the materials? What do you think might work or might not work?
    - What are some of the suggestions in the materials about helping students understand (specific content) at the beginning of this learning set (specific lesson).
    - What do you think might work or might not work?

Follow up to might not work: what the teacher may plan to enact.

1. How do you envision doing this doing the (specific lesson)?
2. How do you envision helping students understand (specific content)?
3. What do you envision students doing?
4. We are interested in why people change things when working with curriculum. I noticed that you said .... Can you tell me about why you changed this?

4. What ideas do you think might be hard for students to understand?
5. Did the materials do anything to add to your understanding of (specific content)?
6. What will students learn from this session? What concepts will they learn? What processes will students learn?
    - How will know (assess) if students are understanding (specific content)?
    - How long do you think this activity will take?
    - How will this help students with their helmet investigation?

Use pages _____ for specific example

7. Would the materials be helpful to someone who doesn't understand? In what way?
8. What would you suggest that would be helpful?

Post-enactment Interview

1. How do you think the lesson went (specific strategie)?
2. What would you change about this lesson?
3. We saw this, why did you do it this way? (specific strategie or content)
4. What do you think students learned in this lesson (specific content)?
5. What do you think students learned by using (specific strategies)?
6. How did the technology help them learn this? (specific content)
7. How do you know if students understand (specific content)?
8. What did you need to know to make this work (specific lesson)? What would have been useful to know before doing this?

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